A GRAVITY SURVEY OF THE PERIDOTITE INTRUSIVES OF ELLIOTT COUNTY, KENTUCKY

A Thesis

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by

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INTRODUCTION

Three intrusive masses of peridotite outcrop in northeastern Elliott County. The northeasternmost, and smallest, is finger-like in form; the other two are irregular and thick-lenticular in surface outline. The intrusives were first discovered in 1884 by Crandall (1885) and are the only known igneous intrusives in eastern Kentucky. Search for diamonds began shortly after Crandall's discovery. A shaft 72 feet deep was sunk into the southeasternmost body but diamonds were never found.

This gravity survey was conducted to detect any gravitational anomalies over the bodies to evaluate the subsurface orientation and the nature of the bodies. To aid in this, a Buoguer anomaly map and a gravity gradient map were constructed. The gravimeter, a Worden Master Geodetic Model, number 602, was provided by the Department of Gology and Mineralogy, The Ohio State University.

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LOCATION

Elliott County falls between Rowan County on the northwest, Morgan on the south and southwest, Lawrence on the southeast, and Carter on the north and northeast (Fig. 1). The peridotite intrusives are in the area 1 to 3.5 kilometers west of Stephens, Kentucky between Ison Creek and Hamilton Creek (Fig. 2). This is in the southwest corner of the Willard 7.5' Quadrangle Map between 83°00' to 83°27' longitude and 38°07'30" to 38°08'30" latitude.

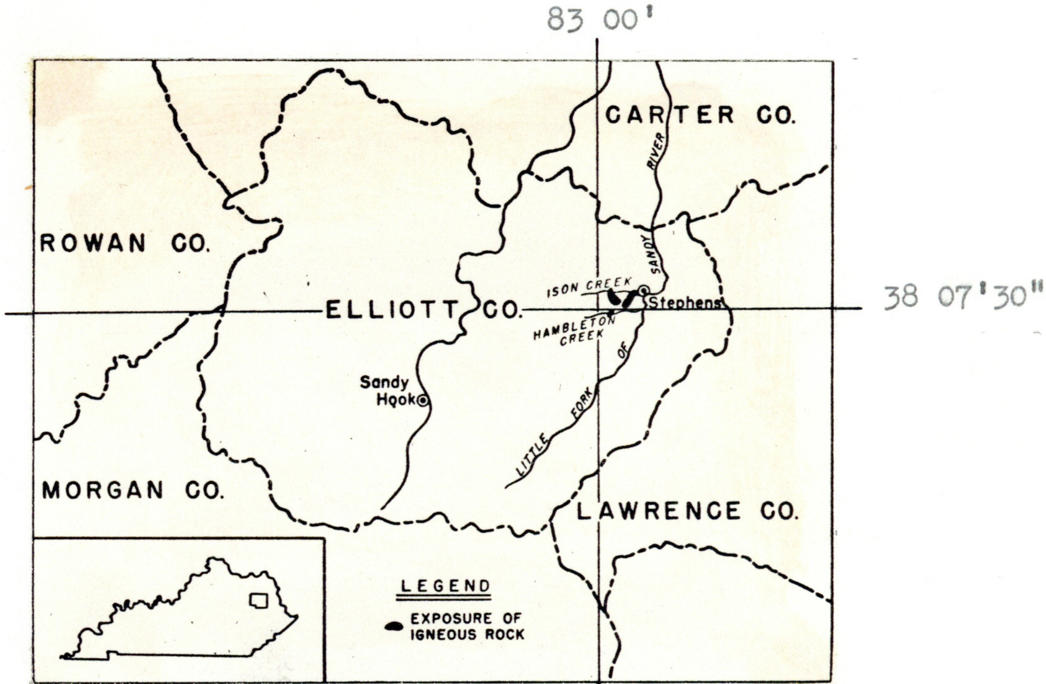

Figure 1. Map of Elliott and surrounding counties, showing relative position of the peridotite intrusions (modified from Koenig, 1956).

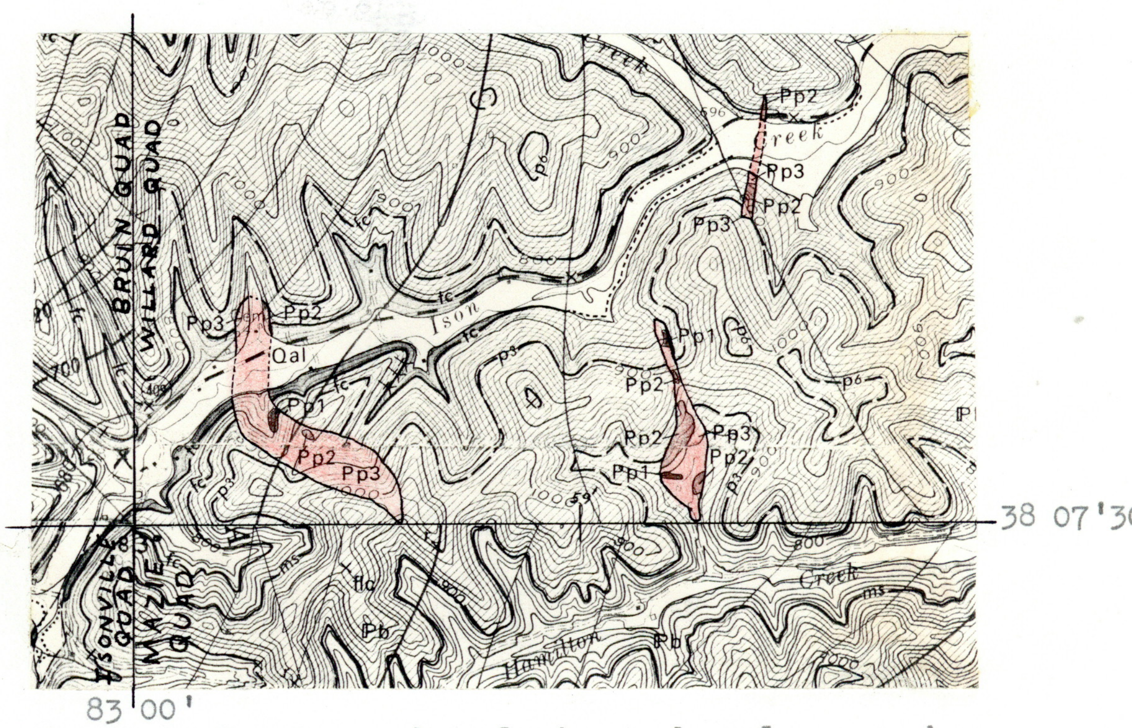

Figure 2. Portions of geologic quadrangle maps showing the intrusive bodies. (1 km = 1.65 in.) Peridotite is shown in red.

GEOLOGY

Introduction

Elliott County is apart of the Allegeny Plateau Physiographic Province characterized by many winding ridges and narrow meandering stream bottoms. There are only small amounts of flat or undulating land. The topography of the survey area ranges from approximately 700 to 1100 feet above sea level.

Structure

Elliott County lies on the eastern limb of the Cincinnati Arch. Locally, the intruded strata is approximately horizontal with little to no structural disturbance from the intrusive event. The regional dip is at a low angle and to the southeast. Four kilometers west of the outcrops is the Trench Anticline trending approximately north-south and plunging north. Four kilometers southwest of the outcrops is the Sandy Hook Anticline trending east-west and plunging east. Dips, in this area, range up to 12 degrees. Three kilometers south of the outcrops is the Little Sandy Fault which is a high angle normal fault trending east-west for approximately 20 kilometers. It is apart of the more extensive Rough Creek-Kentucky River Fault Zone. Displacement, of the Little Sandy Fault, varies from a few feet to 200 feet. The outcrops are on the upthrown side. The peridotite intrusives appear to be unrelated to this structural event except that it appears to occur along a zone of crustal weakness (Diller, 1887, Koenig, 1956).

Stratigraphy

The Pre-Cambrian basement rock, in this area, is of the Grenville Province. The Cambrian, Ordivician, Silurian, and Devonian strata are dominated by limestone and dolomite, with a minor amount of clastics. The lower Mississippian consists of interbedded sandstone and shale. The upper Mississippian, which is the oldest rock exposed in the area, is limestone and dolomite. The Breathitt Formation, of the lower to middle Pennsylvanian, is the youngest rock of the area and the upper limit of intrusive penetration. It consists of a typical coal measures sequence predominantly of sandstone with interbedded siltstone and shale.

Peridotite Petrography

The peridotite has a holocrystalline pophyritic texture with phenocrysts of olivine, garnet, ilmenite, and phlogopite. Phenocrysts make up 60-70% of the rock with sizes ranging from 2-15 mm and rare 25 mm grains. Olivine makes up 45-50% of the rock with serpentine as the alteration product. Serpentine accounts for 25% of the rock which makes the original olivine content nearly 80% (Diller, 1887, Harvey, 1980). Olivine doesn't melt, even under pressure, below 1000 C therefore the peridotite was implaced in a simi-consoladated state. Thin section studies, of the inclusions of the intruded sedimentary rocks(limestone and shale), show no evidence of intense heating and paleomagnetic studies show the peridotite to possess intense non-random magnetization making it imperative that the intrusion was implaced with relatively little movement within the mush-magma (Harvey, 1980). Harvey (1980) contends that the peridotite was probably a "passive" intrusion implaced in a simi-solid state with the major mechanisms being stoping and assimilation of the country rock.

Peridotite Age

Zartman and others (1967) obtained a concordant early Permian age of 269 million years from K-Ar and Rb-Sr dating of xenocrystic biotite from two samples from one of the intrusive masses.

FIELD PROCEDURE

The outcrops, being in the southwest corner of the Willard 7.5' Quadrangle Map, necessitated the joining of three other quadrangle maps. These were the Mazie, Bruin, and Isonville 7.5' Quadrangle Maps. The area of study is confined to 100 square kilometers with approximately 25 square kilometers on each quadrangle map. The study area is centered at the outcrops. Gravimeter readings were taken within each square kilometer except in areas with no access. Along with gravimeter readings, the location, time, and elevation were recorded. Stations were located at known elevations (road intersections) where posible and approximated at others. Error at approximated elevations is ± 2 feet. Base station readings were taken three times a day (beginning, middle, and end) which were used in constructing lunar tide curves.

DATA REDUCTION

The change in gravimeter reading (* reading) is equal to the first base reading of each day subtracted from each additional reading. The change in time (*t) is the time of the base reading subtracted from each additional reading time. This is recorded in minutes and plotted horizontally on a graph. The lunar tide is then approximated using * reading and *t between base stations of the same day with * reading being vertical. The remaining stations are then plotted on the lunar tide curve using *t for positioning. If it's position is on the negitive side of the curve, the correction must be added and if it is on the positive side, subtracted. This corrects for the varying gravitational attraction of the sun and moon which makes all readings as if they were taken at the same time of the day. Also in this step were the corrections of readings to the same day by comparison of the first base readings and either adding or subtracting the difference to bring all first base stations equal. All readings were then corrected similarly by the amount that brought the first base station of their day to the equal of the chosen base station. The value of the readings after the above corrections is then multiplied by the dial constant to equal g. The dial constant is needed to correct for the elastic properties of the spring in the gravimeter and is supplied by Texas Instruments, the maker of the gravimeter. Next, g = (base)-g(observed) is recorded. Then the change in elevation (*h) equal to the elevation observed minus the elevation of the base is recorded. The next correction will bring all stations to one elevation, namely to that of the base station. It is the Free-Air correction (F.A.) which is equal to -0.09138 mgals/ft multiplied by *h(ft). This correction is then added to g(base)- g(observed) to equal the F.A. residuals. An allowance must be made for the gravitational attraction of the slab of material between the base station elevation and the elevations of the remaining stations. This allowance is called the Bouguer correction and involves the density of the material between elevations. The rocks are saturated sandstones and shales so the density was approximated to be 2.4 g/cm^3 or 2.4 kg/m^3. The Bouguer correction (B.A.) is then

$$B.A. = 0.04185 \text{ mgals} \times 2.4 \text{ kg/m}^3 \times 0.3o4 \text{ m/ft} \times *h(ft)$$

The change in gravity from the base station to each other station is equal to the F.A. residual added to B.A. The final correction is for latitude, which was necessary because of the distance covered in the survey(10 km). Latitude corrections were made with respect to the center of the survey (38°07'30") so there was no correction at this latitude. The formula used was $g = A(1-C_2 \sin^2\phi - C_4 \sin^4\phi)$. Differentiating g with respect to ϕ gives $dg/d\phi = AC_2 \sin 2\phi/57.29578$ degrees. With $a = 978.03185$ gals and $C_2 = 0.005278895$,

$$dg/d\phi = 1.502 \sin 2\phi \text{ mgals/min.}$$

Corrections were made for each half minute of latitude with the resulting gravity values being used to construct a Bouguer anomaly map. From the Bouguer anomaly map,a gravity gradient map was made. Values(in mgals/km) result from movement through the Bouguer amomaly map at right angles to contour lines.

CONCLUSION

The Bouguer anomaly map shows a slight widening of contour spacings over the bodies. This may reflect an extremely small gravitational anomaly over the bodies, but cannot be held as conclusive since there seems to be a random widening of contour spacings throughout the survey area. Due to this, a gravity gradient map was constructed to further study the area.

The gravity gradient map reveals a gravitational low plateau over the southeasternmost body extending northeast for about one kilometer in an irregular fashion. The two other intrusive masses show no unusual characteristics. The Little Sandy Fault has a pronounced effect on the gravity but appears unrelated to the intrusive bodies.

The results of the survey show, at most, only a small gravitational anomaly over the peridotite intrusives. This is consistent with their small, finger-like form and suggests they have no great subsurface, lateral extent. The magma source must be very deep, probably mantle derived from a depth of 40 kilometers. These findings agree with those of Harvey (1980) who did an aeromagnetic survey of the same area.

APPENDIX I

Sample Station Data Reduction

STATION	TIME	ELEVATION	GRAVIMETER READING	TEMPERATURE($^\circ$F)
base(1)	7:28	687'	434.8	66
2	7:41	680	449.2	"
base(2)	9:16	687	433.5	"
3	9:40	728	418.4	"
base(3)	1:53	687	435.1	"

The dial constant for 66°F = 0.08571. From here on base will be base(1) and observed(obs) will denote the remaining stations.

* reading = reading(obs) - reading(base)
2 = 449.2 - 434.8 = 14.4
base(2) = 433.5 - 434.8 = -1.3
3 = 418.4 - 434.8 =-16.4
base(3) = 435.1 - 434.8 = 0.3

With a * reading of 0 for base(1) and the above values for bases 2 and 3, a lunar tide curve is constructed. The change in time (*t, horizontal on the graph) is given by

*t = t(obs) - t(base)
2 = 7:41 - 7:28 = 13 min
base(2) = 9:16 - 7:28 = 108 min
3 = 9:40 - 7:28 = 132 min
base(3) = 1:53 - 7:28 = 385 min

Stations 2 and 3 are positioned on the graph using *t. The corrected values are then multiplied by the dial constant to equal g. The below values are then recorded with the change in elevation equal to *h(*h = elev.(obs) - elev.(base)).

	g	g(base) - g(obs)	*h
base(1)	37.27	0	0
2	38.52	-1.25	-7
base(2)	37.26	+0.01	0
3	35.97	+1.30	+41
base(3)	37.26	+0.01	0

The base values show an error of ± 0.01 for g.

Free-Air correction (F.A.) = *h X (-0.09138 mgals/ft)

base = 0 mgals
2 = 0.6397 mgals
3 = -3.7466 mgals

F.A. residuals = F.A. + g(base) - g(obs)

2 = -0.6103 mgals
3 = -2.4466 mgals

B.A. correction = 0.04185 X 2.4 X 0.304 X *h

2 = -0.2143 mgals
3 = +1.2552 mgals

The change in gravity = B.A. correction + F.A. residuals

base = 0 mgals
2 = -0.8246 mgals
3 = -1.1914 mgals

The correction for latitude is given by

$dg/d\phi = 1.502 \sin 2\phi$ mgals/min , ϕ = 38 07'30" = 38.125

$dg/d\phi = 1.502 \sin 2(38.125)$ mgals/min = 1.4590 mgals/min

If the base is at 38 07'30" the gravity remains 0 mgals. If a reading is located north of this, the correction will be the change in gravity of a -1.4590 mgals/ min and if it falls south of the base the gravity will change by + 1.4590 .

Station 2 is 3 minutes north of the base therefore the gravity = -0.8246 - 3(1.4590) = -5.2016 mgals

Station 3 is 0.5 minutes south of the base therefore the gravity = -1.1914 + 0.5(1.4590) = -0.4619 mgals

These are the final gravity values which were used to construct the Bouguer anomaly map.

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